Baryon phase-space density in heavy-ion collisions [1]

Fuqiang Wang and N. Xu

Baryon phase-space density affects the dynamical evolution of heavy-ion collisions from the initial stage to final freeze-out. It is one of the essential ingredients of thermal and chemical equilibrium models often used in studying heavy-ion collisions. The studies of baryon and meson phase-space densities may provide information on particle freeze-out conditions and entropy production in heavy-ion collisions. Here we report a study of the baryon freeze-out phase-space density in heavy ion collisions at the AGS and SPS using experimental data on particle yields and source sizes inferred from two-particle interferometry.

We use a Gaussian form for the particle density profile:

$$f(\mathbf{p},\mathbf{x}) = \frac{E}{m}\frac{dN/d\mathbf{p}}{\left[\sqrt{2\pi}R_G(\mathbf{p})\right]^3}e^{-[\mathbf{x}-\mathbf{x}_0(\mathbf{p})]^2/2R_G^2(\mathbf{p})}. \tag{1}$$

The spatial averaged phase-space density is

$$\langle f(\mathbf{p})\rangle = \frac{\int f^2(\mathbf{p},\mathbf{x})d\mathbf{x}}{\int f(\mathbf{p},\mathbf{x})d\mathbf{x}} = \frac{E}{m}\frac{dN/d\mathbf{p}}{[2\sqrt{\pi}R_G(\mathbf{p})]^3}. \tag{2}$$

It has been assumed that the particles freeze-out at an instant time, and the phase-space density is calculated at that time. When the freeze-out process has a finite time duration, the phase-space density should be considered as a "time-averaged" quantity.

Without knowing the exact form of the space-momentum correlation, $\mathbf{x_0}(\mathbf{p})$, one cannot perform the integration over $\mathbf{p}$. Hence, one cannot obtain the spatial density. However, the operation can be carried out over the spatial coordinate $\mathbf{x}$ leading to Eq. (2).

We assume a m_T exponential transverse distribution, and calculate the averaged phase-space density weighted by particle number density:

$$\langle f(y)\rangle = \frac{T+2m}{8\pi mT(T+m)^2}\frac{dN/dy}{[2\sqrt{\pi}R_G(\mathbf{p})]^3}. \tag{3}$$

We have estimated the freeze-out proton (baryon) as well as pion phase-space densities at mid-rapidity at the AGS and SPS from experimental data [1]. The freeze-out pion phase-space densities at mid-rapidity are similar ($\sim$0.1) for both AGS and SPS energies. But the baryon phase-space density at mid-rapidity is significantly lower than the pion's at both beam energies. On top of that, the mid-rapidity baryon phase-space density decreases as the beam energy increases.

The proton phase-space density can be also obtained from deuteron coalescence [2]. In the coalescence model with a Gaussian density profile,

$R_G^3(\mathbf{p}_\mathrm{p}) = \frac{3}{4}\pi^{3/2}\left(\frac{E_\mathrm{p}}{m_\mathrm{p}}\frac{dN_\mathrm{p}}{d\mathbf{p}_\mathrm{p}}\right)^2 \Big/ \left(\frac{E_\mathrm{d}}{m_\mathrm{d}}\frac{dN_\mathrm{d}}{d\mathbf{p}_\mathrm{d}}\right)_{\mathbf{p}_\mathrm{d}=2\mathbf{p}_\mathrm{p}}$, where the subscripts 'p' and 'd' denote proton and deuteron, respectively. Therefore, the p_T averaged proton phase-space density is

$$\langle f(y)\rangle = \frac{1}{6(2\pi)^3}\frac{(dN/dy)_\mathrm{d}}{(dN/dy)_\mathrm{p}}. \tag{4}$$

Using available deuteron data, we estimated the proton phase-space density at the AGS and SPS [1]. The results are consistent with those obtained using two-proton interferometry data.

We compare our results to thermal model calculations. It is found that the calculated values at chemical freeze-out are higher by a factor of 2.7 ± 1.2 (AGS) and 4.0 ± 1.3 (SPS) than estimated from experimental data. Likewise, the phase-space densities calculated for kinetic freeze-out are higher by a factor of 1.5 ± 0.7 (AGS) and 2.2 ± 1.2 (SPS).

References

[1] F. Wang, Phys. Rev. **C61**, 021904(R) (2000) [Report: LBNL-44128].

[2] P.J Siemens and J.I. Kapusta, Phys. Rev. Lett. **43**, 1486 (1979); **43**, 1690(E) (1979).